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On-farm evaluation of two fast growing trees for biomass production for industrial use in Andhra Pradesh, Southern India

J. V. N. S. Prasad · G. R. Korwar · K. V. Rao · K. Srinivas · Ch. Srinivasarao · B. Pedababu · B. Venkateswarlu · S. N. Rao · H. D. Kulkarni

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Abstract On-farm experiments were conducted in Khammam district of Andhra Pradesh from 2001 to 2006 to evaluate the biomass productivity, intercrop yields and profitability of *Eucalyptus tereticornis* clonal and *Leucaena leucocephala* variety K-636 based systems. Trees were planted at a spacing of 3 × 2 m and evaluated at three locations. Height growth was significantly higher in leucaena during the 4 year where as difference in diameter growth was not significant**.** Biomass partitioning to the bole was high in case of leucaena, ranged from 83% in 2.5–5 cm diameter at breast height (DBH) trees to 89% in 12.5–15 cm DBH trees and in eucalyptus clones the corresponding values were 71% in 2.5–5 cm DBH trees and 83% in 12.5–15 cm DBH trees. Marketable biomass productivity was higher with leucaena (95 Mg ha^{-1}) in comparison to eucalyptus (87 Mg ha^{-1}). Competition effects of trees on intercrops were observed from the 2 year (2002 post-rainy season). Intercrop yields were 45% of the sole crop in eucalyptus system and 36% in leucaena system during the 2 year. Sole eucalyptus and leucaena plantations and intercropping systems recorded higher gross and net returns over arable cropping. Therefore, it can be concluded that leucaena variety K636 and eucalyptus clonal based agroforestry systems are profitable alternatives to arable cropping under rainfed conditions.

Keywords Agroforestry · Biomass · Competition · Eucalyptus · Financial evaluation · Leucaena

J. V. N. S. Prasad (✉) · G. R. Korwar · K. V. Rao · K. Srinivas · Ch. Srinivasarao · B. Pedababu · B. Venkateswarlu
Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, Andhra Pradesh 500059, India
e-mail: jasti2008@gmail.com

S. N. Rao · H. D. Kulkarni
Paper Boards and Specialty Papers Division (PSPD), Indian Tobacco Company (ITC), Secunderabad, Andhra Pradesh 500003, India
e-mail: snraoifs@gmail.com

Introduction

Eucalyptus wood is widely used as a raw material in the manufacture of paper, ply wood, packaging material and in chemical products such as viscose, acetate and cellulose due to its desirable pulp characteristics (Clarke et al. 2008). The eucalyptus tree is also used for sawn timber, mine props, poles, firewood, charcoal, essential oils and tannins (Turnbull 1999; Chen et al. 2007; Sharma et al. 2010). The leucaena tree is primarily used as a source of quality forage for ruminants but it is also valued as timber, fuelwood and a source of charcoal (Pottinger and Hughes 1995). Leucaena is extensively used in alley cropping systems for soil fertility improvement and in soil and water conservation (Mugwe et al. 2010; Kang et al. 1990; Sharma et al. 2010). *Leucaena* wood also has pulp characteristics that make it suitable raw material in the manufacture of paper and packaging material (Malik et al. 2004). Fast-growing trees for biomass production are proposed as an economical and ecological solution to meet the demand for energy and shortage of raw materials for wood-based industries (Licht and Isebrands 2005).

In India, the demand for various kinds of wood is growing rapidly due to the growing requirement for various kinds of paper and also due to the emphasis on paper as an environmentally friendly packaging material. Apart from paper and pulp wood industry, wood is increasingly being used as a substitute for coal in biomass based power generation units due to commitments to reduce greenhouse gas emissions, desire to diversify the supply of energy and uncertainties related to oil price in many parts of the world (Heinimo and Junginger 2009). However, information on the productivity related aspects and relative performance of eucalyptus and leucaena is not available for the large scale cultivation of these plantations. Though eucalyptus clones are reported to produce high biomass (Lal et al. 1997) under experimental trials and high input conditions, little information is available about their performance in on-farm situations under rainfed conditions and their relative performance vis-à-vis *Leucaena leucocephala*, variety K-636. Hence the present investigation was carried out in collaboration with Indian Tobacco company-Paper Boards and Specialty Papers Division (ITC-PSPD) with the following objectives: (1) to study the biomass productivity and partitioning of *Eucalyptus tereticornis* clones *vis-a-vis* that of leucaena variety K-636, (2) to study the performance of intercrops with the two tree species and (3) to determine profitability of these systems for industrial biomass production in comparison to that of the arable crop and sole plantations of these tree species. Experiments were conducted in farmers' fields with the objective of involving farmers in technology development process and for quick adoption of the promising tree species by the farming community.

Materials and methods

Description of experimental site

Experiments were conducted in three farmers' fields in three villages within 50 km distance of each other in Khammam district of Andhra Pradesh, Southern India. The villages are located close to Bhadrachalam town (82°52′05″E and 17°41′19″N), where the paper company, ITC-PSPD is located. While site selection, design of the experiment and data collection were done by researchers, farm operations such as land preparation, tree planting, intercrop sowing, fertilizer application, weeding, harvesting were performed by the farmers under researchers supervision. The experimental sites lie in the alluvial belt of the Godavari river and have a relatively flat topography. The soils are neutral to slightly alkaline (pH 7.0–8.3) and non saline (EC 0.14–0.19 dS m^{-1}), low in organic carbon (0.31–0.58%) and low in available forms of all the three major nutrients (nitrogen 63–100 kg N ha^{-1}, phosphorus 9.6–12.5 kg P ha^{-1} and potassium 75–110 kg K ha^{-1}) in the top 15 cm soil layer. The area receives an average annual precipitation of 1,120 mm, distributed in about 60 rainy days. About 85–90% of the total rainfall is received during June to October. The annual rainfall during the 5 year study period was 1,091, 784, 1,486, 1,058, 1,526 mm in 2001, 2002, 2003, 2004 and 2005, respectively. Mean maximum temperature during the cropping period was 36.2°C and the mean minimum temperature was 17.1°C.

Experimental design

The experiment consisted of two treatments, eucalyptus clones and *Leucaena leucocephala* variety K636. At each of the experimental sites, the area was divided into two equal plots, one for the eucalyptus and the other for leucaena. In each treatment, sufficient area was allocated for the sole trees where intercrops were not grown. Data from the sole trees was used for comparing the productivity and profitability of the sole plantations with that of agroforestry systems. *Eucalyptus tereticornis* clones were selected due to their high biomass production potential and uniform growth. *Leucaena leucocephala* variety K-636 was used because of its desirable characteristics such as low seed production, erect growth with fewer branches. At all the three locations, trees were planted at a spacing of 3 × 2 m and both the tree species were grown. The gross plot size varied between 324 and 1,144 m^2 and the net plot size varied from 60 to 540 m^2 depending up on the space available at each farmer's field.

Tree establishment

Farmers' fields which were not under arable crop cultivation for the previous few seasons were selected for the study. Pits of the size 0.2 × 0.2 × 0.2 m were dug manually and 100 g of single super phosphate was added to each pit and the soil was thoroughly mixed. Three month old 30-cm tall seedlings were transplanted in pits in August 2001. Trees were fertilized annually from 2 year onwards with 23 kg P, and 44 kg K ha^{-1}. Leucaena was applied 23 kg N ha^{-1} during the 1 year and rhizobium inoculation was done after transplanting. Eucalyptus was given a dose of 46 kg N ha^{-1} from the 2 year onwards. Fertilizers were mixed and the mixture was applied in 30-cm deep holes made at a distance of 0.5 m away from the stem on either side of the row, equal quantity to all the trees.

Tree growth and biomass production

Tree height and diameter at breast height (DBH) were measured on five selected trees. Trees were harvested after 51 months in December 2005. At harvest, tree height, collar diameter and DBH were recorded for all the trees in the net plot. Trees were categorized into diameter classes of 5 cm. Diameter classes ranged from 2.5–5 cm to 15–17.5 cm across all the treatments. Trees having diameter equivalent to the midpoint of each class were harvested to study the biomass partitioning and to calculate the total biomass productivity. Based on the data, distribution of trees in the net plot was compiled and percentage of trees according to the DBH class was calculated. Based on the recorded biomass data of tree for each girth class the tree biomass production per hectare was calculated.

Intercrops management

Cowpea (*Vigna unguiculata*) was grown as intercrop during the post rainy season (October–February) in 3 years, i.e. 2001, 2002 and 2003. Sole stand of the test intercrop was grown each season in the same field, away from the influence of trees. The experiment was conducted under rainfed conditions. Cowpea was sown using bullock-drawn implements during the first fortnight of October at a spacing of 30 × 10 cm. Cowpea was supplied with 20 kg N ha $^{-1}$ and 18 kg P ha $^{-1}$ in the form of urea and di-ammonium phosphate basally before sowing. Cowpea was harvested during February at physiological maturity for grain. Samples of green biomass of intercrop and trees were oven dried to convert the fresh weights to dry weights on hectare basis.

Photosynthetically active radiation (PAR) and soil water measurement

PAR was measured during 2001–2002 and 2002–2003 cropping seasons. Measurements were made three times after the sowing of the crop at monthly intervals using a 1.2 m long line quantum sensor. PAR was measured in the tree row and at the centre of tree rows in both the northern and southern directions and also in the open conditions far away from the interference of trees. Light measurements were taken between 1100 and 1300 hours in all the fields. Measurements were made above the cowpea canopy in four directions and the average values of the three observations were taken. The under-storey PAR flux was converted into PAR transmittance, the ratio of PAR below the canopy to PAR incident in the open. Soil water was monitored thermo gravimetrically during 2001–2002 and 2002–2003 cropping seasons at four locations in each tree species: in the tree row, one meter away from tree row in both the northern and southern directions and in the center of two tree rows. Samples were also collected in the open crop conditions far away from the interference of trees. Soil samples were collected from 0 to 30 cm depth at monthly intervals after the sowing of cowpea. The collected samples were weighed immediately and dried to a constant weight for determining water content.

Economics

Financial analysis was performed on different agroforestry systems, compared with sole tree systems and sole annual crops for one harvest cycle of trees. The stream of costs incurred and the direct benefits derived from each system were worked out. Certain products, which do not have any marketable value in the region such as cowpea haulms, leucaena leaves, were not included in the analysis. Biomass of fresh wood and branches were used for calculation of returns. Market costs of inputs and values of outputs prevailing at the end of the harvest cycle (December 2005) were used for the financial analysis. Student's *t* test was used to compare the growth parameters and yields of eucalyptus and leucaena. F test was used to compare the yields of cowpea grown as sole crop and as intercrop in eucalyptus and leucaena.

Results and discussion

Tree height and DBH

Tree height growth was rapid during the 2 year after planting in both the tree species (Table 1). The mean annual height increment was 3.2 m years^{-1} in eucalyptus and

3.5 m years^{-1} in leucaena. Tree height growth was higher during July to December, coinciding with the rainy season than during January to June. Differences in tree height were small during the first 2 years but subsequently leucaena grew significantly taller than eucalyptus. At the time of harvest, about 63% of the leucaena trees attained a height of 14 m, whereas only 47% of eucalyptus of trees attained that height (data not presented). Differences in DBH between the two tree species were not significant (Table 2).

Canopy height and width

Canopy height in various diameter sized trees ranged from 6.7 m in the case of 2.5–5.0 cm diameter trees to 12.0 m in the case of 12.5–15 cm diameter trees in eucalyptus and 5.9 m in 2.5–5.0 cm diameter trees to 10.3 m in the case of 12.5–15 cm diameter trees in leucaena at harvest (Table 3). Canopy width in eucalyptus ranged from 1.7 m in 2.5–5.0 cm diameter trees to 3.1 m in case of 12.5–15 cm diameter trees while in leucaena it ranged from 1.6 m in 2.5–5.0 cm diameter trees to 3.9 m in 12.5–15 cm diameter trees. Differences in canopy height and canopy width between eucalyptus and leucaena were not significant in any of the DBH size classes. However, leucaena produced more branches than eucalyptus. The average number of big sized branches (diameter more than 3 cm) in leucaena was 2.3, 4, 5 and 11 in 5–7.5, 7.5–10, 10–12.5, and 12.5–15 cm diameter trees, respectively. In addition to the large sized branches, leucaena trees had numerous small sized branches. Growth of eucalyptus observed in the present study was greater than that of the trees raised from seedlings at Bijnor (Rawat and Negi 2004), but comparable to that of clonal saplings at Bhadrachalam (Lal et al. 1997).

Table 1 Height growth (m) of eucalyptus and leucaena trees over a 4-year period in Andhra Pradesh, India

Tree sps.	2002		2003		2004		2005	
	January	July	January	July	January	July	January	July
Eucalyptus	1.9	3.1	7.6	8.3	10.1	11.0	12.1	13.1
Leucaena	2.6	3.5	6.8	7.4	10.9	12.3	13.2	14.3
t test (0.05)	NS	NS	NS	NS	NS	*	*	*

* Significant at 5% level of significance

Table 2 Diameter at breast height (cm) of eucalyptus and leucaena trees over a 4-year period (2001–2005) in Andhra Pradesh, India

Tree sps.	2002		2003		2004		2005	
	January	July	January	July	January	July	January	July
Eucalyptus	1.3	1.8	4.6	5.5	8.5	8.8	9.1	9.6
Leucaena	2.4	3.0	5.3	6.1	7.2	7.8	9.0	9.3
t test	NS	NS	NS	NS	NS	NS	NS	NS

Table 3 Canopy height (m) and canopy width (m) of eucalyptus and leucaena trees in different diameter classes at harvest (51 months after planting) in Andhra Pradesh, India

Tree sps.	2.5–5.0 (cm)		5–7.5 (cm)		7.5–10 (cm)		10–12.5 (cm)		12.5–15 (cm)	
	CH	CW	CH	CW	CH	CW	CH	CW	CH	CW
Eucalyptus	6.7	1.7	7.6	1.9	8.5	2.5	11.1	2.5	12.0	3.1
Leucaena	5.9	1.6	6.6	1.8	8.1	2.7	9.0	2.8	10.3	3.9
t test (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

CH canopy height, *CW* canopy width

Biomass production and partitioning

Biomass accumulation in boles increased with the tree diameter in both eucalyptus and leucaena. The mean dry weight of bole was 2.2 kg in the case of 2.5–5 cm DBH, 8.2 kg in the case of 5–7.5 cm diameter, 22.3 kg in the case of 7.5–10 cm diameter, 50 kg in the case of 10–12.5 cm diameter and 66.6 kg in the case of 12.5–15 cm DBH sized trees in eucalyptus. In case of leucaena, the mean dry weight of bole was 3.2 kg in the case of 2.5–5 cm DBH class, 6.7 kg in the case of 5–7.5 cm diameter, 23.6 kg in the case of 7.5–10 cm diameter, 37.1 kg in the case of 10–2.5 cm diameter and 78.7 kg in the case of 12.5–15 cm DBH sized trees.

With increase in DBH, biomass of all the tree components increased significantly. In eucalyptus, the bole accounted for 71% of the total tree biomass in the 2.5–5 cm DBH trees and 83% in 12.5–15 cm DBH trees (Table 4). Bark biomass remained between 8.8 and 6.9% of the total tree biomass where as biomass of branches declined from 17.6 to 5.8% and leaf biomass from 4.8 to 2.7% with the increase in tree diameter. In leucaena, relative biomass of bole to that of total tree biomass ranged from 83% in 2.5–5 cm DBH tree to 89% in 12.5–15 cm DBH tree. Biomass partitioning to branches declined from 8.7 to 3.4% while leaf biomass showed no trend with the increase in tree diameter. Partitioning of biomass to stem increased with the increase in tree diameter in both the tree species. Bernando et al. (1998) also reported increased partitioning of biomass to bole with the increase in tree diameter in *Eucalyptus europhylla*. In the present study, where clones were used, the biomass partitioned into stem (including bark) varied from 78 to 91% where as in seed provenances biomass partitioning has been reported to range from 76 to 79% to stem,

Table 4 Biomass partitioning into different components (in percentage) in various diameter classes at harvest (51 months after planting) in Andhra Pradesh, India

Tree sps.	Diameter of stem (cm)	Stem	Bark	Branch	Leaf
Eucalyptus	2.5–5.0	70.8	6.9	17.4	4.8
	5–7.5	79.4	7.5	6.4	6.3
	7.5–10	83.6	6.4	5.6	4.5
	10–12.5	82.2	8.5	5.6	3.7
	12.5–15	82.7	8.8	5.8	2.7
Leucaena	2.5–5.0	82.8	3.8	8.7	4.7
	5–7.5	80.5	7.9	8.9	2.6
	7.5–10	87.1	4.8	5.2	2.8
	10–12.5	90.2	2.5	4.7	2.6
	12.5–15	89.4	2.8	3.4	4.3

Table 5 Fresh and dry biomass of eucalyptus and leucaena at harvest in Andhra Pradesh, India

Tree sps.	Marketable biomass (bole) Fresh wt Mg ha^{-1}	Dry biomass (Mg ha^{-1})				
		Bole	Branch	Leaf	Bark	Total
Eucalyptus	86.7	44.6	4.2	1.5	4.6	54.2
Leucaena	94.8	52.1	2.6	1.4	2.4	58.5
t test (0.05)	*	*	NS	NS	NS	NS

* Significant at 5% level of significance

5.6–6% to leaf and 15–18% to branches (Lalji et al. 2005). It appears that eucalyptus trees raised from seedlings partitioned more of the biomass into branches whereas clonal trees accumulated more biomass into the bole and leaves.

As eucalyptus and leucaena are primarily used as raw material for the manufacturing of paper and packaging material and also in energy production, the bole is the marketable product. In the absence of any specifications from industry on minimum diameter size of the stem for pricing, the total wood production is the primary criterion for evaluating trees. In this study, the marketable biomass of leucaena (94 Mg ha^{-1}) was significantly higher than that of eucalyptus (Table 5), mainly due to the substantial contribution of leucaena branches to the marketable biomass.

Differences in wood production between the two species can be partly explained by the relative size distribution of trees and canopy characteristics. Trees in eucalyptus had relatively higher DBH in comparison to leucaena. For example, in eucalyptus, at the time of harvest, 72% of trees attained a DBH of 7.5–15 cm where as it was only 63% in case of leucaena. Trees with greater DBH have higher weight per plant and contribute to the increase in tonnage. However, leucaena trees produced more number of branches which were absent in case of eucalyptus clones. The average number of marketable branches (DBH more than 3 cm diameter) range from 2.3 in case of 5–7.5 cm DBH trees to 11.3 in case of 12.5–15 cm DBH trees. The biomass of branches contributed substantially to the total biomass productivity of leucaena in comparison to eucalyptus. The study showed that leucaena variety, K-636 and eucalyptus clones in a 4-year rotation under on-farm situations has the potential to produce up to 95 t ha^{-1} of fresh biomass in a 4 year period. The results of this study are of importance on future fibre and wood supply and carbon sequestration. It is clear that the productivity of short rotation plantations with suitable management practices can greatly exceed that of native forests (Hunter 2001).

Intercrop yields

Intercrop yields were not influenced by tree species in the first cropping season (post-rainy season of 2001). Ceccon (2008) also did not observe intercrop yield reduction in eucalyptus system during the 1 year of tree growth. The adverse effect of trees on intercrops was observed from the 2 year (i.e. 2002 post-rainy season) onwards. During this season, the grain yield of cowpea in eucalyptus was 45% of the sole cowpea while in leucaena it was 36%. The extent of yield reduction was greater in the crop rows nearer to the tree rows. In the post rainy season of 2003, cowpea yields were reduced drastically. In 2004, cowpea failed to establish in leucaena whereas in eucalyptus crop growth was poor. The magnitude of crop yield losses in agroforestry systems are known to increase with the age of the trees due to the increased size of the trees and their ability to draw resources at the expense of

Table 6 Cowpea yields (kg ha^{-1}) in leucaena and eucalyptus during 4 years (2001–2005) of study in Andhra Pradesh, India

Systems	Post rainy season 2001	Post rainy season 2002	Post rainy season 2003	Post rainy season 2004
Eucalyptus + Cowpea	879	296	121	134
Leucaena + Cowpea	1,015	235	76	–
Sole Cowpea (crop without tree)	968	650	706	584
F test (0.05)	NS	*	*	*

* Significant at 5% level of significance

crops (Dhyani and Tripathi 1999). Adverse effects of trees on intercrops are expected to be high in the post-rainy season, when trees compete with crops for the limited stored soil moisture (Table 6).

Light interception

During the first year of cropping (2001), the first crop row close to the trees received 91% of the open radiation on an average as the trees grew only 2.0 m tall. The centre of tree rows received close to 100% of the open radiation. However, during the second year (2002), the amount of radiation reaching the crop rows near the trees decreased up to 70%. The reduction in radiation was more in leucaena than in eucalyptus. Leucaena put forth dense foliage during the rainy season which resulted in considerable reduction in light transmitted to the crop underneath. During the third year of tree growth, the canopy growth was profuse in case of leucaena causing severe obstruction to light for the crop underneath. In the present study, tree shade got extended up to the center of alley by the second year of tree growth. Shade affects the growth and development of crop plants adversely, the effect being more pronounced in grain crops than in fodder crops (Wong 1991).

Soil water availability

Soil moisture in 0–30 cm layer decreased as the cropping season progressed in the second year of cropping. In both eucalyptus and leucaena, soil moisture content at the centre of alleys was lower when compared to the crop rows nearer to the tree, at 30 days after sowing of the intercrop. At 90 days after sowing also, the same trend was observed, but the differences became smaller (data not presented). Crop rows closest to the trees on both sides were worst affected and failed to put forth normal vegetative growth. Crop rows up to 1 m from the tree row suffered from reduced light as well as from the water stress, due to competition from trees. In the present study, seedlings of cowpea adjacent to leucaena rows grew poorly and remained stunted throughout the season from the second cropping season. The effect was severe during 2003 post rainy season, which received only 784 mm of rainfall with 42 rainy days as against the average of 1,119 mm with 68 rainy days. Negative effects of trees on seasonal crops due to competition for water were widely reported semi arid climates (Rao et al. 1991).

Financial evaluation

In 2001, the year trees were planted, the high cost of the planting material, especially the eucalyptus clones, their transportation to the field, digging of pits and planting resulted in large negative returns from eucalyptus and leucaena under both the sole tree and agroforestry situations (Table 7). In that year, the sole crop of cowpea gave a net positive returns of Rs. 10,886 ha^{-1}. The agroforestry systems had lower negative returns compared to the sole tree systems as the cowpea intercrop yielded income. Though biomass yields were higher with leucaena, returns were higher with eucalyptus due to the higher prices offered for eucalyptus wood. Net returns were negative for intercropping in both the tree species during the initial 2 years in spite of intercrop yields due to higher initial plantation establishment costs and lower intercrop yields. Although intercropping gave some returns, but could be obtained only during the initial 2 years. Intercropping in eucalyptus gave net returns of Rs. 87,503 over a 4-year period while in case of leucaena it is Rs. 78,780. Returns from intercropping eucalyptus and leucaena were comparable to the sole eucalyptus system (Rs. 80,435) but considerably higher than the returns from sole arable cropping (Rs. 27,440).

Eucalyptus plantations are retained for a period of 16 years with 4 harvests at 4year interval and leucaena plantations are retained for 10 years with three cycles of harvest. As the cost of planting material is only in the 1 year (of the first cycle), returns from tree systems in subsequent cycles would be much greater compared with arable crops. Some additional labour may be required to manage the coppice shoots during second to fourth cycles but its cost may not be higher than the labour required during the first establishment cycle. The tree + intercrop systems required about 55 man days labour ha^{-1} year^{-1} compared to 37 man days ha^{-1} year^{-1} for sole leucaena and 29 man days ha^{-1} year^{-1} for sole arable cropping. Some of the operations like pitting for tree planting, debarking in case of eucalyptus, wood harvesting and loading into tractors demand heavy labour input. Tree harvesting provides employment for labour during October to January, when other avenues for employment are unavailable in rural areas. All the financial indicators show that eucalyptus and leucaena agroforestry systems are more profitable than arable cropping and sole tree cropping. Similar conclusions were also made in eucalyptus and in poplar (Singh et al. 1997) grown for wood production. Intercropping in the initial years allows better cash flow during the initial years of plantation cycle when the returns from tree are not forthcoming (Table 8).

Table 7 Financial analyses of different agroforestry and sole tree systems in Andhra Pradesh, India

Systems	Total costs (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})					Total net returns (Rs.ha^{1})
			Year 1 (2001)	Year 2 (2002)	Year 3 (2003)	Year 4 (2004)	Year 5 (2005)	
Agroforestry systems								
Eucalyptus + Cowpea	70,275	157,774	−10,941	−3,965	−4,366	−3,853	110,629	87,503
Leucaena + Cowpea	49,588	128,368	−6,020	−2,335	−5,197	−2,709	95,041	78,780
Sole eucalyptus	49,545	129,980	−22,325	−3,205	−3,205	−3,205	112,375	80,435
Sole leucaena	38,011	104,500	−20,425	−2,709	−2,709	−2,709	95,041	66,489
Arable cropping (Cowpea)	30,842	58,282	10,886	5,671	7,524	5,160	1,801	27,440

Price of Eucalyptus wood is Rs. 1,340 Mg^{-1}, leucaena wood Rs. 1,100 Mg^{-1}, 1US \$ = Rs. 48, Cowpea Rs. 18,000 Mg^{-1}

Table 8 Benefit/cost ratio (B:C) and net present value (NPV) of net income at different discount rates for two tree systems in Andhra Pradesh, India

Systems	6%		12%		18%	
	NPV	B:C	NPV	B:C	NPV	B:C
Agroforestry systems						
Eucalyptus + Cowpea	62,074	2.1	44,237	1.9	31,584	1.7
Leucaena + Cowpea	56,730	2.3	41,228	2.1	30,195	1.9
Sole eucalyptus	54,808	2.3	36,905	2.0	24,292	1.7
Sole leucaena	44,903	2.3	29,838	2.0	19,240	1.7
Arable cropping (Cowpea)	24,374	1.9	21,859	1.9	19,750	2.0

NPV net present value, *B:C* benefit/cost ratio

Conclusions

The adoption of planted forests has started increasing with the expanding market for the wood, high biomass productivity and profitability of tree systems with that of arable crops and the proximity of the market in the form of paper industry. However, among the two tree species, the biomass productivity and partitioning into stem were higher with leucaena where as the gross and net returns were higher with the eucalyptus system due to the higher prices offered for eucalyptus wood. The kind of tree species to be selected depends on the end use of the wood and the prevailing market prices. Eucalyptus is a better choice provided market opportunities exist for props, scaffolding or for pulpwood and packaging material. Leucaena is a better choice if the end use of wood is for heating or as pulpwood with fodder. Intercropping in the narrow rows is possible only during the first season in both the tree species. For small holders where annual returns from intercropping are the main criteria, tree geometry needs to be altered and wider row tree planting could be an alternative. Leucaena and eucalyptus based agroforestry systems in marginal lands are profitable alternatives for crop diversification for improving the income and integrating wood and food production for smallholder situations.

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